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# Environment Models in War Games

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# Abstract

Atmospheric and environmental phenomena have been portrayed in most military war games. In ModSAF, for example, models and representations can be found for the change of illumination levels on objects due to solar and lunar motion and weather influences (such as rain, sleet, and snow), and the obscuration impacts of smoke, dust, and haze. Newer models have been developed that more accurately portray the turbulence and radiative transfer within these common atmospheric and environmental phenomena. However, frequently these models cannot be directly substituted into the war games, either because the data interfaces are wrong or because the model may adversely affect the performance of the war game model itself.

This report examines a number of war games, including CASTFOREM, JANUS, ModSAF, JSIMS, and JMASS, to determine how environment is currently played in these games. The focus here is on the specific environmental submodels that are part of the EOSAEL and WAVES modeling packages. It was found that these atmospheric models are not used as originally developed; they were modified to accommodate the requirements of the war games. Other mechanisms for the interface between the models are discussed. An alternate, promising approach for an interface was introduced with the development of the TAOS software. However, limitations to the efficacy of the interfaces persist.

# Contents

# 1. Introduction

In the world of computer modeling, new models and new methods of simulation are created just as older processes are put into practice. The replacement of the older models with new ones is not always an easy process. This is especially true for models that simulate the battlefield. War games are becoming more realistic and more accurate, and they frequently demand interactive participation; this affects the inputs required for the simulation. The data inputs for the models that interface with newer simulations must support a more detailed description of the scenario being represented. In addition, these new models can seriously inhibit the simulation's ability to perform in real time.

This report discusses a number of the new Army atmospheric models developed in recent years and if, and how, these models can interface with several of the more popular war games. The report is not exhaustive—it does not attempt to cover all war game models in existence, nor does it examine all available atmospheric models. Section 2 gives a rationale for selection of the models included here, lists the environment parameters of immediate interest, and discusses the significance of environment in modeling.

Section 3 gives an overview of each war game model and an analysis of the way each model characterizes atmospheric phenomena.

Section 4 describes several atmospheric models, both those currently part of war game simulations and some newer models now available for incorporation into existing simulations. While the details of how each model computes the output from the inputs are not of interest in this report, the specific input requirements for each model are important and the limitations of the output information can be significant. In addition, the Total Atmosphere Ocean Services (TAOS) modeling service is described.

A brief discussion is included in section 5 on the different methods available for interfacing the models with each other. This very important section shows why several changes are needed in the structure of the atmospheric models and points out studies that must be performed. Finally, in section 6, several conclusions from this study are presented.

# 2. Methodology

## 2.1 Model Selections

Specific war game models were selected for this analysis, some because they were already available on ARL computer systems and some because they were easy to install and use. In addition, it was important to include at least one that was not an Army system. Two models were already installed on the ARL system: ModSAF and CASTFOREM. Two other models, JANUS and JMASS, were immediately available and relatively easy to install. A fifth model, JSIMS, represents the leading edge of technology and supports all the services.

Our choice of atmospheric models is based on the Electro-Optical Systems Atmospheric Effects Library (EOSAEL) suite of models and the models that have been developed to update this suite. However, not all 24 models that the EOSAEL suite comprises are discussed. Three atmospheric models were selected that the author expects will have a direct bearing on the war game models: First, the COMBIC model is discussed, since this model determines the growth and extinction characteristics of obscurants that appear on the battlefield. Second, the XSCALE model is considered, since this model computes the line-of-sight (LOS) transmission between two points through the atmosphere under varying environmental conditions (such as rain, snow, and fog). Finally, the LOWTRAN/MODTRAN model is reviewed, since this model computes the extinction coefficients of the atmosphere. While these three models make use of other EOSAEL models, the remaining models in EOSAEL are not frequently called by the war games. One additional suite of atmospheric models, the Weather and Atmospheric Visualization Effects for Simulation (WAVES), is discussed. WAVES is scheduled to be part of an update for many of the models that make up EOSAEL.

## 2.2 Atmospheric Parameters

During a war game, two major environmentally dependent events need frequent evaluation: whether a target can be detected by the weapon system and whether forces can be moved on the battlefield. The latter can be determined by the mobility models available to the war game and will not be discussed further here. This report addresses target detection by a weapon system.

Target detection and identification procedures need to consider the transmissive characteristics of the intervening medium between the target and the sensor. The intervening medium will reduce the relative signal

strength, both by scattering energy out of the signal and by scattering background noise in. Basic parameters needed to characterize normal atmospheric structure include atmospheric temperature, pressure, and humidity. When deliberate attempts are made to modify the atmospheric characteristics by generating smokes or other gaseous obscurants, wind speed and direction also become important. Nature also introduces large scattering particles on its own—snow, rain, and other forms of precipitation will cause further obscuration. Of course, the time(s) of the obscurant's deployment and material type needs to be specified. The inadvertent actions of the target/sensor can also modify the standard atmosphere. Dust generated by vehicle movement requires information of the soil type over which the vehicle is moving. Finally, the target signature can be altered both by natural environmental changes and by the random, turbulent movement of the atmosphere. Illumination levels will vary depending on the nature of the cloud cover and the cloud height, as well as the specific time of day (or night) and the day of the year.

Table 1 lists environmental parameters that can be important for the depiction of atmospheric phenomena. The table indicates the parameters that are taken as input by the war games and models being considered in this report.

**Table 1. Atmospheric parameters used as input data in various models.**

| | Models | | | |
|---|---|---|---|---|
| Parameters | ModSAF | Janus | CASTFOREM | TAOS |
| Albedo | | | | |
| Barometric pressure | X | | X | X |
| Cloud cover | X | | | X |
| Cloud height | | | | X |
| Cloud ceiling | X | X | | X |
| Cloud type | | | X | X |
| Extinction coefficient | X | X | | X |
| Extinction type | X | | | X |
| Illumination | X | X | X | |
| Precipitation type | X | | X | X |
| Precipitation rate | X | | | X |
| Relative humidity | X | X | X | X |
| Sky-ground ratio | X | X | X | |
| Structure constant | | | | |
| Temperature—local | X | X | X | X |
| Temperature profile | | | | |
| Temperature dew point | X | | | X |
| Visibility | X | X | | |
| Wind direction | X | X | X | X |
| Wind speed | X | X | X | X |
| Wind variance | | | | |

## 2.3 Environmental Impacts

Generally, there is no question that environment can have a strong effect on the evolution of a war game. Rain will slow the advance of a force or make it difficult to detect a target. A change in wind direction can blow an obscurant in the wrong direction or alter the range of a weapon system. However, how accurately does the phenomenon have to be represented in the war game? If the phenomenon is nonlinear, a small change in the input can lead to radically different results. If one force has weapon systems that have a longer range, but does not have a target detection capability to take advantage of the circumstance because of the weather, it will be essential to represent the environment accurately.

Sensitivity of a war game to changes in the environment is scenario-dependent. If a battle is being fought at short range, wind speed will not be a factor in the flight of munitions. Changes in light level will not be important for a brief battle, but they can be a factor if the battle takes place at sunset or sunrise. Ideally, the system performance would be represented under the specific, existing environmental conditions. This capability is unlikely for two reasons. First, it is unlikely that the system performance is known and modeled for all possible encounters. If the performance of a system during an engagement can be represented by an analytic equation, it may be possible to evaluate the equation in time to react appropriately. However, most system performances are based on a lookup table at some point in the computation, and specific values are not present. Second, environmental data are available only at specific spatial points and at specific temporal points. This unevenness of the database can have strong effects.

An example of how the database influences a scenario is given by a recent study [1] that modeled the use of smoke during a breaching operation (using the Army's Grizzly vehicle). The environmental data were obtained from the Navy's Coupled Ocean Atmospheric Mesoscale Prediction System (COAMPS) database. This database can be modeled as both a 27-km resolution database and a 9-km database. Because of the roughness of the terrain in the area being modeled, two different wind velocities (with changes in both direction and speed) were modeled, according to which database was selected. These differences in terrain would not have occurred if the scenario had taken place on the plains of Kansas. The result of these differences in wind velocity, caused by the difference in resolution of the databases, significantly altered the appearance of the smoke on the battlefield. In both cases, the smoke obscured the threat to the Grizzly. However, in one case the minefield to be breached by the Grizzly was clear of the obscuring smoke, and in the other case it was not clear for the operation.

# 3. War Game Models

## 3.1 ModSAF

ModSAF [2] is designed for use on a network, with participants located throughout the world. As such, it requires real-time performance for all the interactive participants. The latest version of this model is version 4, released in April 1998. A newer version, version 5, is already scheduled for release in 1999. The model is written in the C programming language and runs on a number of Unix-based platforms, including Sun and Silicon Graphics.

A player in the simulation is located at a workstation that displays a map of the engagement terrain. The same screen displays a set of tools for updating and controlling the entities under the control of this workstation. The player normally views only the forces he creates and any forces within his viewing capability. If the appropriate information is communicated over the network, other forces—controlled by other workstations or representing actual forces training on the battlefield—can be placed on the display. Each player generates the orders for the forces played from his workstation, determining where, when, and how far his forces move. If the forces have weapon systems, he can also generate the commands that determine their engagement rules.

The table in section 2.2 shows the atmospheric parameters represented in ModSAF 4.0. Those parameters are used when ModSAF simulates such phenomena as illumination from solar, lunar, and man-made sources, and obscuration from smoke, boundary-layer aerosols, and precipitation. There are two options for how the weather and these parameters are to be played. The state of the weather can be defined by parameters set by the user, or by a source of "live" data, such as TAOS. The default values for ModSAF correspond to an exercise running on a clear, sunny day.

Illumination levels are determined from an ephemeris model, Solar/ Lunar Almanac Core (SLAC), and the Natural Illumination Under Realistic Weather Conditions (ILUMA) model. These models, part of the EOSAEL suite of models, will support cloud cover and precipitation. Within ModSAF, ILUMA is implemented as a set of three precomputed lookup tables. The first table is for the solar illumination, the second for the lunar illumination, and the third for background sky illumination.

Atmospheric transmission is determined from two EOSAEL models (LOWTRAN and XSCALE) and a third model, called BCIS, which is used to determine the transmissivity of a dust storm. Again, within ModSAF, precomputed lookup tables are used for the extinction coefficients.

Obscuration, caused by battlefield smoke and dust, is provided by the EOSAEL model, Combined Obscuration Model for Battlefield-Induced Contaminants (COMBIC). This model has two parts: The first part models the time evolution of smoke and battlefield clouds generated by battlefield sources. The second part computes the transmission along a path between two points that pass through the obscurant. In ModSAF, this model is implemented in two different ways. For phase 1, the results are precomputed as a set of lookup tables. For phase 2, the actual COMBIC code is included as a separate module.

Phenomena that are *not* treated in ModSAF include turbulence, shadowing, and acoustics. The effect of turbulence will be to distort the appearance of an object and cause the apparent LOS to be different from the true LOS. Additional information is required in order to characterize this effect, in particular, the atmospheric structure constant. Shadowing alters the light level illuminating a target object and, therefore, the ability to detect and identify the object. However, all information required to treat this phenomenon is already available. Acoustic sensors are not directly modeled within ModSAF. Acoustic detection is normally short range and, therefore, is not a significant factor in influencing the outcome of a battle.

## 3.2 JANUS

JANUS was developed as an interactive war game before the development of the network [3]. The players are located in the same general area, but at three separate stations. One station is for the Blue players, one for the Red players, and one for a referee. The need for a referee arises because of the analytical intent for using the game. When a player makes a poor military choice, the game can be stopped and restarted with a more viable military strategy. Also, the same game is usually played several times, to allow statistical variations to affect how the player responds to altered situations. The players very quickly learn the intent and strategy of their opponents, and begin to take advantage of their fortuitous knowledge. The referee is necessary to control the military validity of each player's visionary strategies.

Several environmental effects are simulated. A capability exists for the portrayal of different levels of illumination, smoke, and dust. The ability to control illumination level settings first became available in version 6.88 of JANUS [4]. When the simulation is started, an illumination level is selected, and this value is maintained throughout the simulation. Different illumination levels can be selected with an appropriate minimum resolvable contrast (MRC) database for each optical sensor used during the simulation. Since a simulation normally covers only 10 to 20 minutes of real time, the constant value is a reasonable approximation. However, a partly cloudy day that generates changing illumination levels cannot be realistically represented. When the illumination level changes, a target that is detectable under direct sunlight may not be detectable under a cloud shadow.

Smokes [5] are played by having a rectangular-defined volume appear for a defined length of time. The size of the volume and the duration depend on the nature of the smoke (HC (hexachloroethane), WP (white phosphorus), or other) and the method of dispensing (grenades, smoke pots, vehicle emission, and others). This volume is defined to be opaque and will block any LOS that passes through the volume.

Acoustics phenomena were played in JANUS, but only as a one-time modeling task that evaluated the performance of a special sensor using acoustic systems. The sensor performance was played by using lookup tables that presented the detection range for the sensor as a function of the different target types. Computations for this lookup table were performed before the JANUS run, with an early acoustic detection model called the Acoustic Detection Range Prediction Model (ADRPM). This simulation demonstrated the methodology for incorporating special phenomena into JANUS, and the acoustic model is not known to remain in the simulation.

## 3.3 CASTFOREM

The Combined Arms and Support Task Force Evaluation Model (CASTFOREM) [6] was developed in the early 1980's. This model is a high-resolution, two-sided, force-on-force, stochastic systemic model of a combined arms conflict. When it was first developed, the software was written in the SIMSCRIPT II.5 computer language and was run on a Sun IV 310/330 computer. There is no direct player involvement during the computer run. The use of decision tables and an embedded expert system implement the effects of tactics. The result of the algorithm determines the battlefield control.

Most Army entities are represented in the war game by suitable models, although some sensor phenomena do not have a representation. For example, acoustics is not considered during the play of a game in CASTFOREM. The reason for this lack of representation is the short range of sensors that use this capability and the nature of the scenarios being considered. Usually, large open areas are modeled, where optical and radar sensors will be able to perform the significant target detection and acquisition roles. However, in an urban battlefield, an acoustic sensor capability could become tactically significant.

Environmental effects such as wind, time of day, and day of the year are played, but only statically. That is, once the parameters are initially set, there are no changes in the values. Smoke and dust are represented in CASTFOREM by full usage of the COMBIC model. A constant wind speed and direction are assumed within the model.

## 3.4 JMASS

The Joint Modeling and Simulation System (JMASS) [7] is not a model by itself. Rather, it is a programming environment that can be used in the development of a model that will be used for the evaluation of the performance of weapon systems. The system provides all the tools necessary for a program written either in C++ or Ada programming languages. A modeling library is an important aspect of this system. The library contains reusable model components, whole models, stored scenarios, and other parts of the system.

This model is not a real-time model. Once the model components are assembled and compiled, the program will run until completion. There is no direct interaction by a user during the run. However, initialization parameters can be changed and the program rerun without repeating the compilation procedure. This makes the model an excellent analysis tool for evaluating the effectiveness of system characteristics.

Environmental information can be easily incorporated into JMASS. The design of the software requires [8] that a capability exist to specify the pressure, temperature, and concentration of atmospheric constituents versus altitude, season, and geographic location. Each of the molecular constituents included will have a detailed molecular absorption database. Aerosols can be described with regard to their vertical profile, size, composition, and refractive indices. Cloud-free LOS statistics can be specified as a function of geographic location, season, and local weather. Rain and snow can be represented in terms of the size distribution and precipitation rates. Finally, a user can specify the solar and lunar flux in the visual and infrared wavelength regions.

As part of the standard model, an "IR atmosphere player" is included [8]. This model uses one of three atmospheric propagation models: Quick IR, MODTRAN, or Quick_TRAN. The Quick IR routine is an independent set of subroutines that calculates the effective target irradiance in various IR bands. MODTRAN is a standard set of code for the computation of atmospheric transmittance and solar and lunar radiance values. Finally, Quick_TRAN uses precomputed values (using MODTRAN) to interpolate values for the irradiance.

## 3.5 JSIMS

The Joint Simulation System (JSIMS) [9] is the next generation of large-scale distributed training simulations. The software for this model will not be completed before the year 2000. At present, the architectural structure for this system has been defined and code is being written. However, information to definitively state the environmental factors the model embraces is not available.

Similar to the JMASS model, JSIMS will contain a system library to assemble needed components for a simulation. This library (called the JSIMS Modeling and Simulation Resource Repository (JMSRR)) is fully integrated into the Object-Oriented Frameworks collection of software classes, which permit the interfacing of other software into the overall structure of the simulation. Frameworks is described as being "user supporting." TAOS is an example of the software that will be incorporated.

# 4. Atmospheric Models

## 4.1 COMBIC

COMBIC [10] is a two-phase model for computing the growth of battlefield obscurants, such as dust and smoke, and determining atmospheric extinction along a user-determined LOS. The model has evolved through several versions, from 1982 to 1992. Source code is written in FORTRAN 77.

Because COMBIC is a two-phase model, the possibility exists for separating the model into two parts. The first phase computes the growth and location of the cloud, under the influence of diffusion, gravity, and external winds. A basic assumption for the computation is that the cloud is an ellipsoidal, Gaussian distribution. The physical equations that describe the growth will maintain the Gaussian form of the result, although the parameters describing the shape will deform. Results of this computation are placed into an auxiliary database that is indexed based on the time since the cloud was started. This database is available and necessary for the performance of the next phase.

The second phase of COMBIC computes the transmittance between target and observer for the clouds defined under the first phase as a function of time. If several clouds are present and growing, the transmittance through all intervening clouds is computed. These computations can be performed for multiple wavelengths. The computational speed for this second phase of the algorithm is essentially real time.

## 4.2 XSCALE

This model computes the slant-path atmospheric transmittance through naturally occurring aerosols such as haze, fog, rain, and snow. There are several versions of the model: XSCALE 87, XSCALE 89, and XSCALE 92. The different versions reflect improvements in the experimental database used to compute the semi-empirical coefficients contained in the model. Within the spectral band covered by this model (0.2 to 12.5 mm) substantial changes have been made to some of the parameters, and it is recommended that the most recent version of XSCALE be used for reliable results.

XSCALE is written in FORTRAN 77. Aerosols are assumed to be horizontally homogeneous, and Beer's law is used to calculate horizontal transmittance. For slant paths, where the value for the extinction coefficient may vary, extinction is obtained by using the average extinction along the path. While there are default values present for all variables, one of the more important variables required by the model is the visibility. Outputs from the model include the extinction, scattering, and absorption coefficients averaged over the path and the wavelength band.

## 4.3 LOWTRAN/MODTRAN

Since the late 1960's, the Air Force has been developing a series of models [11] that compute the extinction coefficients for the atmosphere. The Low-Resolution/Moderate-Resolution Transmittance (LOWTRAN/MODTRAN) code is a band model for the computation of radiative transfer through the atmosphere. Written in FORTRAN, the code computes the spectral transmission based on the molecular composition of the atmosphere. This model has become a standard model for atmospheric transmission computations throughout Department of Defense (DoD) modeling.

## 4.4 WAVES

The WAVES [12] suite of models predicts illumination and radiance information for a three-dimensionally variable atmosphere. WAVES incorporates cloud type and partly cloudy skies in its functionality and predicts electro-optical propagation effects for horizontal and slant paths through the natural atmosphere. Also, WAVES performs calculations on both computer-generated synthetic images and real sensor images.

This model is an enhancement of the EOSAEL suite of models. The major advantage of WAVES when compared to EOSAEL is in the radiative transport computations. Within the EOSAEL models, the assumption is made that only single scattering of radiation will take place. WAVES solves the radiative transport equations and will, therefore, include multiple scattering phenomena.

## 4.5 TAOS

The TAOS system [13] is really not a model. It is an "environmental data service to provide a consistent detailed, dynamic description of the combined atmosphere-ocean-littoral natural environment, using 4-D grids (three spatial dimensions plus time) to provide a common representation of the environmental base fields and embedded feature." The system functions as an on-line source for environmental data. Some of the environmental parameters TAOS supplies are shown in table 1 in section 2.2. These are the atmospheric parameters that were used in the Synthetic Theater of War (STOW) environmental Federation Object Model. The

TAOS system was developed with object-oriented design principles and implemented in the C++ language.

Data in the TAOS database are continually updated through links to live observations from operational sources (such as the Automated Weather Network), through links to the gridded forecast products from the Defense Modeling and Simulation Office (DMSO) Master Environmental Library, and by means of models that are part of the system. One model that will become part of the system is the WAVES model described earlier.

# 5. Model Interfaces

The manner in which different atmospheric models are incorporated into war games is a function of the computational speed required of the model. In a ModSAF simulation, the need is for real-time operation of the model, since players actively participate. On the other hand, CASTFOREM is a closed simulation, requiring no external interaction once the simulation is started. The speed of the model can be as slow as the user is willing to tolerate.

There are several ways a model can be interfaced into a simulation. The fastest computational speed can be implemented by use of a lookup table. However, this implies that the specific data that will be needed have been anticipated and computed in advance. When radical events occur (such as may happen with the direction of motion and extent of strong storm centers, or an innovative strategy of a player), the correct data might not be available. A good method must be available for extrapolating the available data to cover the missing information.

At the other extreme, the slowest computational speed occurs when the analytic model is used in its entirety. However, the advantage is that it does not require large data arrays to cover all possible contingencies. In addition, as newer, more effective models are developed, it becomes easier to incorporate modifications.

A possible method to work around both the real-time requirement and the large array limitation is to divide the model into separate modules. The longest computational portions are precomputed and included in the model as a lookup table. For example, a model such as COMBIC can require long periods of computational time to execute and could not be implemented directly in ModSAF. Instead, the first phase of COMBIC, which computes the growth of a cloud due to diffusion and gravitational effects, is precomputed and placed into a lookup table that is indexed on the relative time the cloud has been growing. A rapid computation can then be made of the atmospheric extinction values between an observer and a target using the second phase of the COMBIC code. Not all models can be easily segregated into separate modules. For example, WAVES models depend heavily on the Boundary Layer Illumination and Radiative Balance (BLIRB) [14] computational model. This model is not a real-time component and cannot be subdivided into real-time subunits.

Another way of arranging the interface is to have another computer preparing the requisite information (that is, parallel processing). This approach is being followed in a number of recent games, by querying the TAOS system for the desired information. Because the exact values of all data points where information is required do not conform with the data points where information is computed by TAOS, consideration must be given to a careful crafting of the interfaces between the computers. For example, suppose the background radiance is needed in a dusty environment. By interfacing with TAOS and using TAOS to compute the values with the model BLIRB in 10-min update intervals, a war game could be improved by having accurate, real-time background radiance values.

Finally, another way to form the interface is to develop a statistical database in conjunction with a standard initialized database. That is, if you know that the last reading of the variable has a specific value, then the next value to be used (other than the correct computed next value) is based on a statistical draw from possible next values. This approach has not been tested in any games and is presented only as a topic for further investigation.

# 6. Conclusions

Most modern war games include a capability for representing environmental effects. In the games examined in this report, most of the environmental models that are part of the EOSAEL suite of models are used in one form or another and integrated directly into the war game. A major deficiency in the war game models is their inability to represent acoustic phenomena. This deficiency arises from the types of scenarios that are of primary concern to the war games: an acoustic sensor does not impact the events as they occur within the war games.

Another deficiency that exists in the environmental models in war games is the representation of turbulence. While turbulence does not introduce errors in short-range encounters and does not occur in many battlefield scenarios, the phenomenon can introduce serious aim-point errors in the performance of long-range weapon systems. This phenomenon has been observed on the battlefield.

The development of newer models, intended to replace the older versions of EOSAEL models, presents a different problem. Many of the EOSAEL models have been modified in order to conform with the interface requirements of the war game model. What this implies is that newer suites of environmental models, such as WAVES, will not be able to be substituted directly for the earlier suites without additional developments of the appropriate interfaces. Some of this interface problem will be resolved by the use of other software. At present, the intent is to use TAOS in the war games as the appropriate interface; WAVES will become a part of TAOS, and TAOS will handle the necessary interfaces. This will place a responsibility on the newer environmental models to meet the interface

requirements of TAOS, so that users will not have to be concerned about the specific needs of all existing war games.

One problem that needs to be addressed is both the need and the methodology required for extrapolating data from an environmental database. The need for extrapolating data is determined by the sensitivity of the simulation to the changes in the environment. A radical change in the environment will have a significant effect on the performance of a system. For example, an electro-optical sensor will not perform well if the scenario takes place during an overcast night, but it will perform very well in a sunlit scenario. There will be a definite need to correctly represent this change in illumination. On the other hand, if the change in illumination takes place in a 10-min interval, the value taken at the start of the interval is probably adequate for the entire interval. This sensitivity must be evaluated on a simulation-by-simulation basis.

For example, if the need exists for extrapolating the environmental data during sunrise or sunset when an optical sensor will have its performance change rapidly and extensively, an algorithm needs to be part of either the simulation or the data source to generate the appropriate value. There are many excellent algorithms for extrapolating information, depending on how many prior data points are available. TAOS has many routines for interpolating data from historical data. However, it is not known whether the same routines can be used for extrapolating to future times. It may be possible to incorporate these same extrapolation routines into individual simulations.

The war games examined here all make an effort to portray environmental factors. The major apparent deficiency is in the categories of acoustic sensors and turbulence. Newer model developments will require attention to the TAOS modeling environment to ensure capability with the input and output needs for that database. Finally, for support of those systems that do not interface with the TAOS database, some research should be done on statistical databases to see if they can fulfill the real-time needs of environmental interfaces.

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Atmospheric and environmental phenomena have been portrayed in most military war games. In ModSAF, for example, models and representations can be found for the change of illumination levels on objects due to solar and lunar motion and weather influences (such as rain, sleet, and snow), and the obscuration impacts of smoke, dust, and haze. Newer models have been developed that more accurately portray the turbulence and radiative transfer within these common atmospheric and environmental phenomena. However, frequently these models cannot be directly substituted into the war games, either because the data interfaces are wrong or because the model may adversely affect the performance of the war game model itself.

This report examines a number of war games, including CASTFOREM, JANUS, ModSAF, JSIMS, and JMASS, to determine how environment is currently played in these games. The focus here is on the specific environmental submodels that are part of the EOSAEL and WAVES modeling packages. It was found that these atmospheric models are not used as originally developed; they were modified to accommodate the requirements of the war games. Other mechanisms for the interface between the models are discussed. An alternate, promising approach for an interface was introduced with the development of the TAOS software. However, limitations to the efficacy of the interfaces persist.

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